Gas and Dust in the Magellanic Clouds

A Synopsis of Thesis

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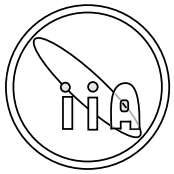

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Title of the thesis	:	**Gas and Dust in the Magellanic Clouds**
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Summary

Interstellar medium (ISM) is the space between the stars comprising of atoms, molecules and ionized gases at various temperatures, and dust grains that contain a large fraction of the elements heavier than hydrogen and helium. Although dust grain accounts for only 1% of the mass of the ISM, it obscures celestial objects in visual and ultraviolet (UV) wavelengths of the elctromagnetic spectrum and reradiates the absorbed energy in the infrared wavelength. Diffuse UV light is dominated by radiation from hot stars scattered by interstellar dust grains. The intensity of this background radiation depends on the distribution of hot stars, amount and distribution of dust, optical depth and the optical parameters of dust.

The Magellanic Clouds (MCs) are nearby extragalactic objects which provide a very different view of the ISM compare to either the Milky Way or any other distant galaxies. Due to the face on view, proximity and low level of obscuration of the MCs, it has been feasible to study the small scale structures and emission processes of the ISM of them without any confusion along the line of sight. We have studied the FUV diffuse emission from the MCs that is dependent on the relative geometry of the dust and the stars. We have also presented a survey of O VI absorption in the Large Magellanic Cloud (LMC) which is a tracer of hot gas in the ISM.

Serendipitous observations made with the *Far Ultraviolet Spectroscopic Explorer (FUSE)* have been used to report measurements of the diffuse FUV (1000 - 1150 Å) emission from the MCs. We have followed the analysis method of Murthy & Sahnow (2004) to extract the diffuse surface brightness from the *FUSE* spectra. We obtained 81 suitable FUV diffuse observations in different parts of the LMC and 30 observations in various environments of the SMC. The intensities of FUV diffuse radiation measured from the *FUSE* data range from around 10^3 photons cm^{-2} s^{-1} sr^{-1} Å^{-1} to as high as 3×10^5 photons cm^{-2} s^{-1} sr^{-1} Å^{-1} in both the LMC and the SMC. We obtained a good correlation between *FUSE* diffuse radiation and the diffuse radiation measured from *Ultraviolet Imaging Telescope (UIT)* and then estimated the fraction of radiation that is emitted as diffuse emission from both the galaxies. These fractions range from 5% to 20% of the total integrated emission at 1100 Å, with a high of 45% in the superbubble N70, with an observed error of 12 – 17%. The shape of the diffuse fraction is same in all the 10 *UIT* regions rising by a factor of about 5 from 1000 to 1500 Å, suggesting that most of the heating of the interstellar dust comes in the FUV. This is in good agreement with the lower albedo and higher cross-section of the grains in the FUV obtained from the model calculations of Li & Draine (2001).

The diffuse FUV fraction in the SMC ranges between 34% – 44% in the *FUSE* bands (1000 – 1150 Å) with a further increase upto 63% at 1615 Å. In case of the SMC, the behaviour of the diffuse fraction is almost the same as the LMC, rising by 10% from 1000 Å to 1150 Å and a further 50% from 1150 Åto 1615 Å, suggesting that the albedo of the dust increases by about the same factor. The FUV diffuse emission in the H II regions of the SMC correlates nicely with the Hα emissions suggesting that much of the Hα emissions is a result of dust scattering and the FUV diffuse emission indirectly traces the star formation in the H II regions.

The behaviour and distribution of FUV diffuse emission and Diffuse fraction are quite similar in both the LMC and the SMC. It is also seen that much of the stellar radiation in the MCs is non-local i.e., the diffuse (scattered) light in a particular region is the light coming from distant stars being scattered by local dust. The diffuse fraction in the SMC is higher than the LMC which is attributed to the relatively higher value of albedo of SMC dust compared to the LMC dust and also to the less number of hot stars in the SMC compared to the LMC.

Interstellar dust manifests itself by interaction with ambient radiation field of ISM and plays an important role in over all energy balance of ISM either by heating or cooling the ISM. Five times ionized oxygen (O VI) is a tracer of hot gas at a temperature of around $3\times$ 10^5 K. High resolution absorption spectra taken by *FUSE* for 70 lines of sight have been used and a wide survey of O VI column density measurements for the LMC is presented using Howk et al. (2002); Savage & Sembach (1991) and Savage & Sembach (1992). The O VI column density varies from a minimum of log N(O VI) $=$ 13.72 atoms cm^{-2} to a maximum value of log N(O VI) $=$ 14.57 atoms cm^{-2}. A high abundance of O VI both in active (super bubble region) and inactive regions of the LMC is found. The abundance and properties of O VI absorption are similar in the LMC and the Milky Way (MW) despite the fact that the LMC has lower metallicity than the MW. O VI absorption in the LMC does not correlate with Hα (warm gas) or X-ray (hot gas) observations but shows correlation with X-ray in 30 Doradus region, the most active region of star formation in the LMC and the O VI column density decreases with an increase in angular distance from the star cluster R136 suggesting some correlation with stellar radiation field.

Outline of the Thesis

This thesis covers the serendipitous observations of the FUV (1000 – 1150 Å)

diffuse emission from the MCs. An extensive survey of O VI absorptions analyzing *FUSE* spectra for 70 different locations of the LMC has been presented. A summary of each chapter of the thesis is given here.

Chapter 1

Chapter 1 comprises of an overview of the ISM and the interstellar dust grains. The properties of gas components at different temperature of the ISM and dust grain properties such as dust extinction, emission, absorption, scattering, polarization and distribution are described. Various heating and cooling mechanisms that are responsible for the energy transportation in different phase of the ISM by means of atoms, molecules, ions and dust grains are explained.

Chapter 2

In chapter 2, a brief history of the recent observations of UV diffuse emission along with its various components are described. The cosmic UV emission and its relation with emission at other wavelength (IR and HI) in the ISM is presented. A description of the *FUSE* and *UIT* instruments, observations and the data reduction procedures are delineated. The *FUSE* data analysis and selection criteria of the diffuse observations has been elaborated and the theory of the Stellar Radiation Field Model that is used for the stellar flux calculation in the *FUSE* bands is derived.

Chapter 3

Chapter 3 begins with an introduction and literature survey of the LMC. UV studies of the LMC, the distribution and properties of FUV diffuse emissions concluded by our results is described in detail. The correlation of the *FUSE* diffuse flux with the *UIT* flux, calculation of diffuse fraction at different *FUSE* bands, and the variation of diffuse fraction with wavelength is explained.

Chapter 4

In chapter 4, we have given an introduction to the SMC. Then we have discussed the observations of FUV diffuse emission, calculation of diffuse fraction, its regional variation, correlation of diffuse flux with Hα flux is explained. Finally, a comparison of FUV diffuse emission with the LMC is given.

Chapter 5

Chapter 5 presents a survey of O VI in the Large Magellanic Cloud. A brief descriptions of the previous studies of O VI in the MW, the LMC and the SMC is given. The data selection and reduction procedures of the O VI absorption profile is discussed. Possible contaminations to the O VI absorption profile followed by measurements of equivalent width and O VI column density (N(O VI)) is presented in detail. Over all the distribution of O VI in the LMC is compared with the MW and the SMC. Correlation of N(O VI) with X-ray and H_α is studied in order to search for ionized structures in LMC. Finally, the properties and distribution of O VI in specific regions like superbubbles and 30 Doradus are described.

Chapter 6

Chapter 6 summarizes the complete thesis work and conclusions of our results of FUV diffuse observations in the MCs and the O VI absorption in the LMC. The future work to be carried out are also outlined.

List of Publications

1. "Far Ultraviolet Diffuse emission from the Large Magellanic Cloud", *Ananta C. Pradhan, Amit Pathak, & Jayant Murthy*, 2010, ApJ Letters, 718, 141 – 144.

2. "Survey of O VI absorption in the Large Magellanic Cloud", *Amit Pathak, Ananta C. Pradhan, Sujatha, N. V. & Jayant Murthy*, 2010, MNRAS, 412, 1105 – 1122.

3. "Observations of Far Ultraviolet Diffuse Emission from the Small Magellanic Cloud", *Ananta C. Pradhan, Jayant Murthy & Amit Pathak*, To be submitted.

4. "Survey of O VI emission in the Small Magellanic Cloud", *Amit Pathak, Ananta C. Pradhan & Jayant Murthy*, manuscript under preparation.

5. "New light on star birthplace", *Ananta C. Pradhan, Amit Pathak, & Jayant Murthy*, Nature India, doi:10.1038/nindia.2010.96; Published online.

6. "Far Ultraviolet Characteristics of the Interstellar Medium of the Magellanic Clouds", *Amit Pathak, Ananta C. Pradhan & Jayant Murthy*, Book Chapter under preparation for Nova Science Publishers, Hauppauge, NY 11788-3619, USA.

References

- Draine, B. T., & Li, A. 2001, ApJ, 551, 807
- Howk, J. C., Sembach, K. R., Savage, B. D., Massa, D., Friedman, S. D., Fullerton, A. W., 2002, ApJ, 569, 214
- Murthy, J., & Sahnow, D. J. 2004, ApJ, 615, 315
- Savage, B. D., Sembach, K. R., 1991, ApJ, 379, 245
- Sembach, K. R., Savage, B. D., 1992, ApJS, 83, 147